MODELING THE CAPTURE OF COSMIC DUST PARTICLES IN AEROGEL

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Cosmic Dust

The science of Exobiology, the study of the origins and distribution of life in the universe, has a very special relationship with the element Carbon, one of the main building blocks of life on Earth. Carbon and carbon compounds from extraterrestrial sources are of special interest, both for comparison with Earth's carbon compounds (which have been processed by biological activity for millennia) and as possible sources of some of Earth's prebiotic compounds. Cosmic and interplanetary dust are exceptionally interesting as a source of prebiotic compounds because the size of the dust particles enables some of them to be brought to Earth intact, without the high temperature atmospheric processing characteristic of larger meteorites.[1]

Although dust is ubiquitous in the universe, the structure and chemical composition of cosmic and interplanetary dust are not well characterized. The most common method of collecting these particles involves impact collectors which use a thin layer of silicone oil. Unfortunately, this oil contaminates the sample and prevents analysis of a critical region of its spectrum.[1] The need for uncontaminated cosmic dust samples has prompted the study of Aerogel as a capture medium.

Aerogel

Aerogels are sol-gel derived, supercritically dried materials with extraordinarily large porosity, i.e. low density. As such, high velocity collisions of particles (such as cosmic or interplanetary dust particles) with aerogel may result in particle capture with minimal thermal processing of the particle. Since aerogel can be manufactured with very low levels of contamination by organics or by silicone oil, the chemical properties of particles collected in it may be determined with greater certainty.

Experiments with particle impacts into aerogel have been limited to velocities less than about 7 km/s. Since collisions between an Earth-orbiting collector and an interplanetary dust particle may be at speeds as high as 72 km/s (for a particle in a retrograde parabolic orbit), high velocity impact characterization would be useful in analyzing aerogel's potential as a dust collection medium. Computer modeling of aerogel impact experiments could yield an understanding of the impact characteristics throughout the expected range of velocities, but have so far produced less than satisfying results.

The CTH Model

We have been modeling aerogel/particle impacts using a Coupled Thermodynamic and Hydrodynamic code known as CTH. Developed by Sandia National Laboratories for the United States Department of Defense, CTH is a flexible software system designed to treat a wide range of shock wave propagation and material motion phenomena. Equations of state for the modeled materials are specified either analytically or in a tabular (SESAME) format. Other physical parameters and initial conditions for each material are specified in an input script for the CTH program. The program then calculates material positions, densities, temperatures, pressures, etc. at subsequent times.[2]

One impact experiment in particular was chosen as the test case for the model because of the amount of data available on it. This experiment involved a roughly spherical 0.00103 g Carnelian particle 0.92 mm in average diameter which was shot into aerogel at a velocity of 3.58 km/s. The target was a high purity (better than 1 PPM) silica aerogel in the form of a cylinder 8 cm in diameter by approximately 12 cm high with a density of 0.0648 g/cm3. The impact track formed was 8.25 cm long with an average entrance diameter of 2.7 mm. The particle was recovered from the aerogel intact, with the leading edge encased in a thin layer of glass.[3]

The model uses a quartz equation of state (SESAME table) for the impactor. The aerogel, however, employs a porous material/two-state option of the CTH program which allows the material to be described by two different equations of state.[4] The low-density initial state of the aerogel is described by an analytical (Mie-Grüneisen) equation of state while the tabular SESAME equation of state for quartz is used for aerogel material that has been compressed or melted.

Results

Figure 1 shows temperature in the aerogel and impacting particle 20 µs after impact. At this time the particle has slowed from its initial 3.58 km/s to 0.94 km/s Although the aerogel in the shock region in

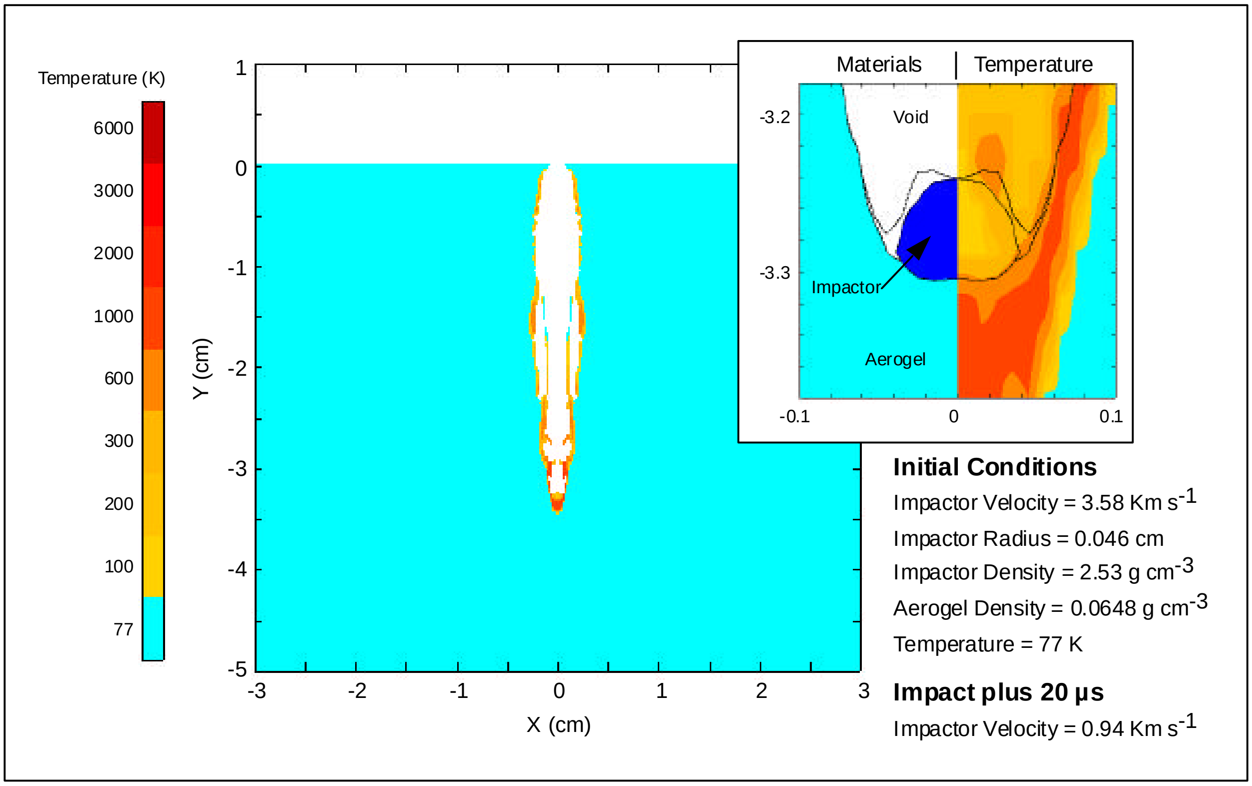

Figure 1: CTH generated values of aerogel and impactor temperature 20 µs after impact

front of (below) the impactor approaches the melting point, the temperature of the impacting particle itself is below 600K, well below the melting point of quartz.

In the high velocity impact experiments, a glassy coating was found to cover the front of the impactor after it was recovered from the aerogel. This sheath of glass is thought to have been formed of silica aerogel material that was compressed and melted by the pressures and temperatures in the shock region in front of the particle which then hardened into this glassy coating against the cooler impactor. This coating probably acts as a protective layer for the impactor, guarding it from further abrasion.

The current configuration of the CTH program does not correctly model the formation of this glassy sheath. As a result, the particle in this model disintegrates before it comes to rest in the aerogel target.

One probable cause of this difficulty is in the elastic-plastic calculation. Although the CTH program allows two states of one material to be described by two equations of state, the elastic-plastic properties of a material are defined by one equation. With further study, we hope to identify a relationship for yield stress based on temperature and density that more closely approximates the elastic-plastic properties of aerogel in these impacts. An additional source of error in our calculation is in the equation of state for aerogel. We are in the process of obtaining new equation-of-state data for silica aerogel from Neil Holmes at Lawrence Livermore National Laboratories. If these improvements to the CTH modeling effort do not increase the fidelity of the model, other modeling options should be considered to describe these high velocity impact/capture events in silica aerogel.

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[3] D. J. Mendez, "Physical Characterization of SiO_2 Aerogel: Phase I Final Report," Lockheed Missiles and Space Company report LMSC-P016695P, January 1995

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